Ultra-fast & Ultra-sensitive Nanostructured Hydrogen Sensors

Tao Xu[a], Michael Zach[a], Zhili Xiao[a,b], Daniel Rosenmann[a], Ulrich Welp[a], Wai-Kwong Kwok[a], G.W.Crabtree[a]
[a] Materials Science Division, Argonne National Laboratory
[b] Department of Physics, Northern Illinois University

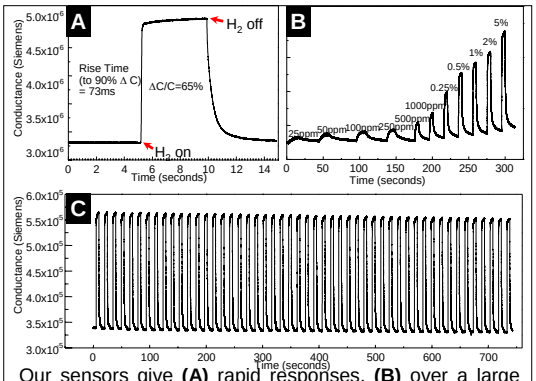
Motivation: To develop fast and sensitive hydrogen sensors that will be critical safety components to our new "Hydrogen Economy."

- **Existing commercially-available sensors are unacceptable**
  - Slow (generally >10 seconds for a full scale response)
  - Low sensitivity (few sensors are capable of measuring below 1% concentration)
  - Energy inefficient (requiring consistent high temperatures to function)
  - Expensive (not mass producible or requiring cumbersome optical or mass spectrometry detection)
- **Hydrogen properties require an ultra fast and sensitive method for sensing**
  - 4-75% concentration in air limits of flammability (sensors needed to detect well below the lower limit)
  - 18-59% concentration in air limits of detonation (sensors need to detect very rapidly)
  - Low minimum ignition energy compared with other gaseous fuels (critical need for accurate detection)

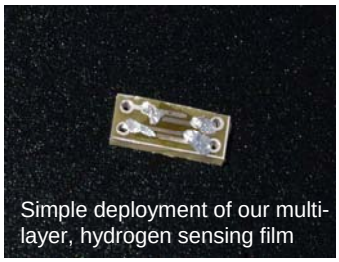
Ignition of 20cm balloons containing flammable mixtures of gas: A) Pure H_2 must mix with air to below 75% before it ignites and burns for 0.50 seconds. **B)** A 2:1 mixture of H_2 and O_2 detonates with a considerable shockwave and flames lasting 0.07 seconds **C)** 10% H_2 In air burns poorly without an explosion in 0.12 seconds. Below 4% in air H_2 is inherently safe.

Major Accomplishments:

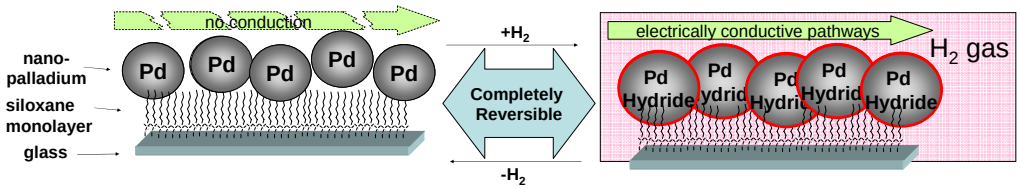
- Created the World's fastest, highly-selective, low-power, commercially-producible hydrogen sensor
  - + <75mS response with 2% hydrogen
  - + detection of 25ppm H_2 without elaborate signal amplification
  - + highly-selective, robust and reproducible response to H_2 gas
- Identified a suitable self-assembled siloxane monolayer that modifies nanoscale morphology of palladium
- Found industrial partners that are interested in investing in the commercialization of this technology



Our sensors give **(A)** rapid responses, **(B)** over a large dynamic range, **(C)** with a robust reproducible signal.



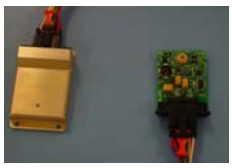
Simple deployment of our multi-layer, hydrogen sensing film



Simple mechanism: an 11% lattice expansion when H_2 is present closes gaps between slightly mobile nanoscale palladium beads

Impact:

+ Numerous inquiries from companies ranging from startups to major auto manufacturers
+ Signed agreement with Makel Engineering to exclusively license the patent rights
+ Follow-on funding in the form of Phase I and II with our industrial and funding partners Makel Engineering and EMTEC.
+ Submission of our sensors for an R&D100 award.



MAKEL ENGINEERING
EMTEC

An automotive system prototype that will employ our sensor technology

Future Directions: In addition to the commercialization of this technology, we are investigating other applications of hydrogen sensing. Ideas such as a hydrogen dosimeter, creating sensors that detect processes emitting H_2 as a byproduct, and methods for deploying the ultra-rapid and ultra-sensitive hydrogen sensors are being explored.

T. Xu, M. P. Zach, Z.L.Xiao, D.Rosenmann, U.Welp, W.K.Kwok, G.W.Crabtree, Self-Assembled Monolayer-Enhanced Hydrogen Sensing with Ultrathin Palladium Films, Appl. Phys. Lett. 86, 203104 (2005)*

ARGONNE NATIONAL LABORATORY

This work was supported by the U.S. Department of Energy, Basic Energy Sciences, under contract W-31-109-ENG-38.

THE UNIVERSITY OF CHICAGO

Office of Science U.S. DEPARTMENT OF ENERGY